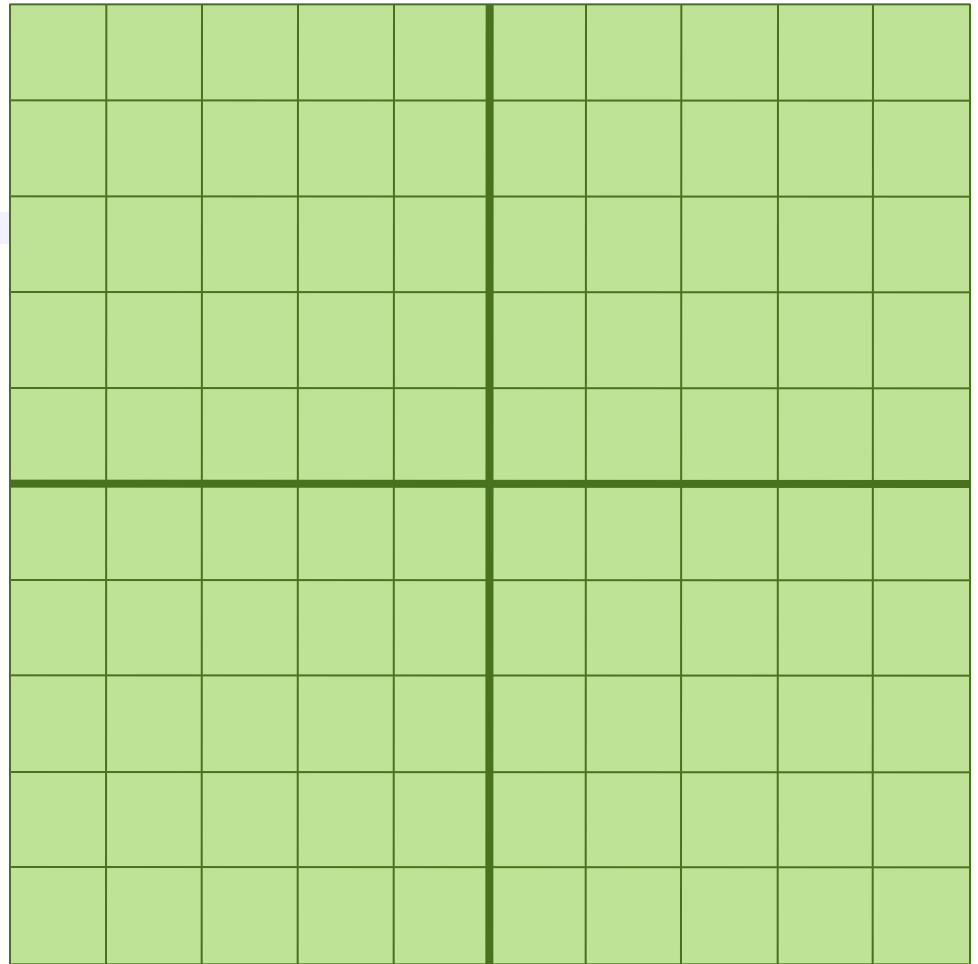# Hierarchical Modeling

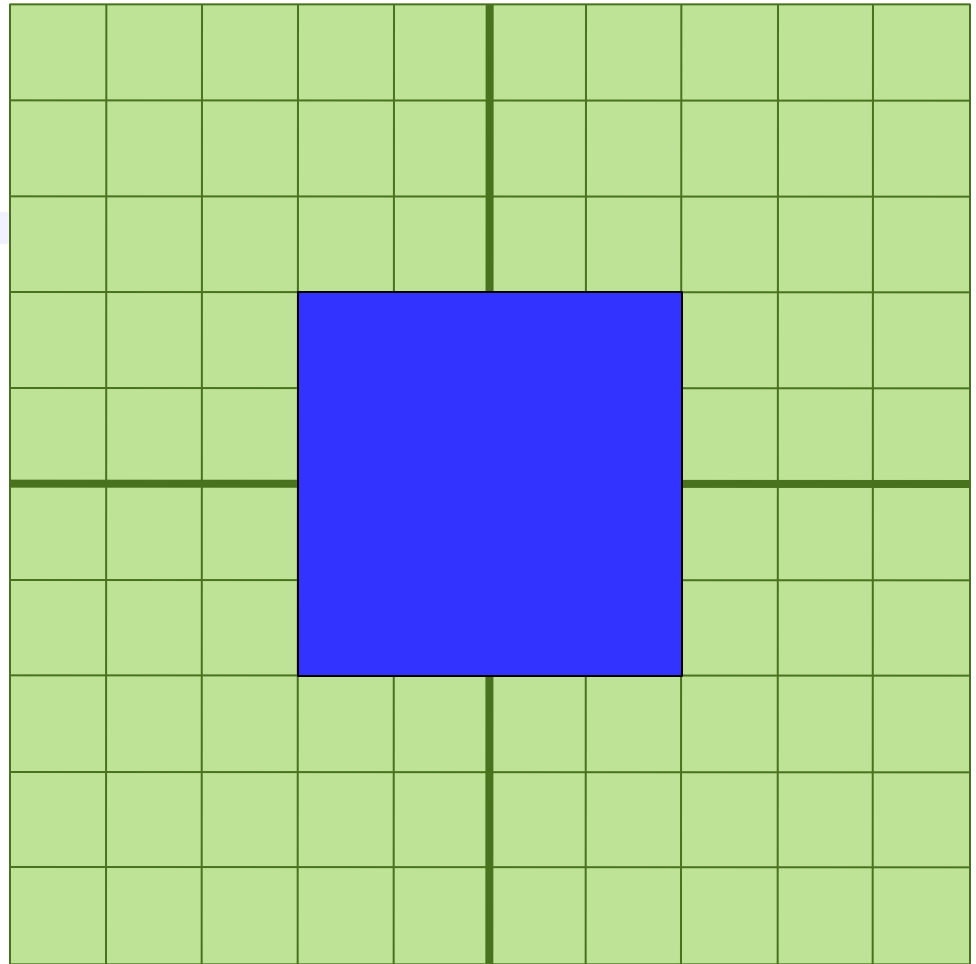CS418 Computer Graphics

John C. Hart

Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```
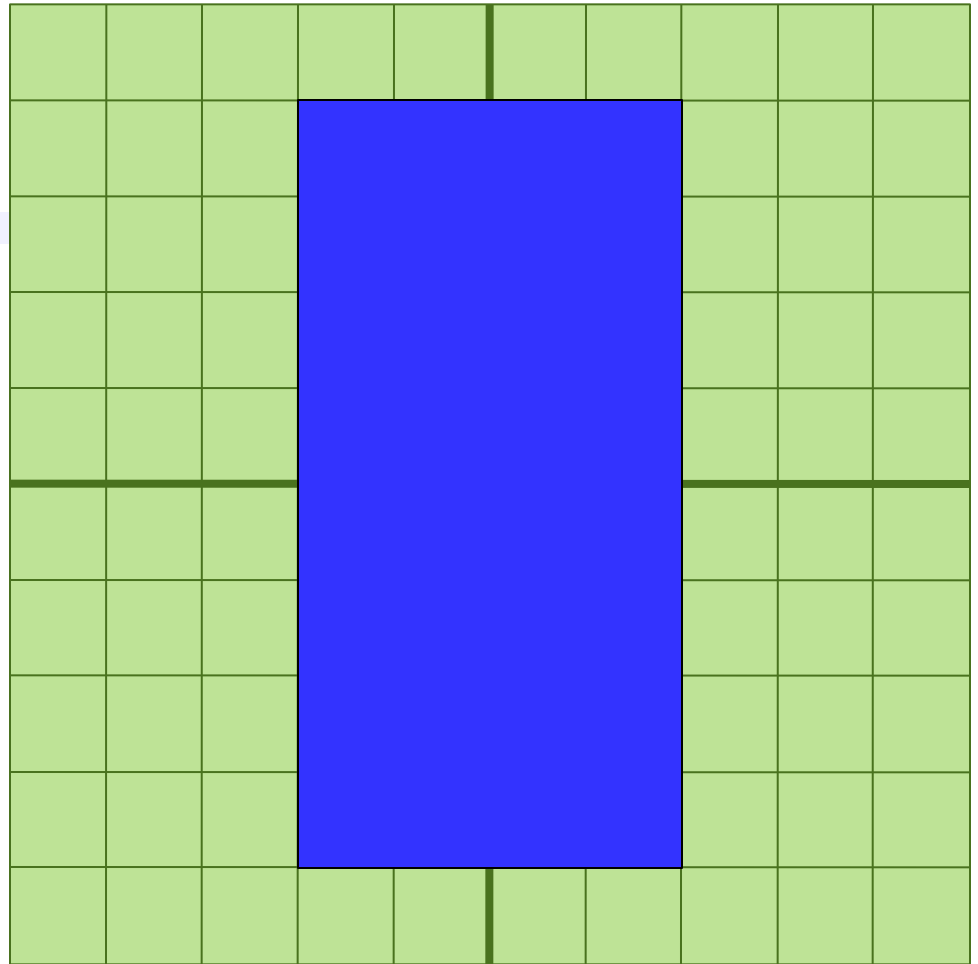
Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```


$$\blacksquare = \begin{bmatrix} 1 & & & \\ & 2 & & \\ & & 1 & \\ & & & 1 \end{bmatrix} \times \blacksquare$$
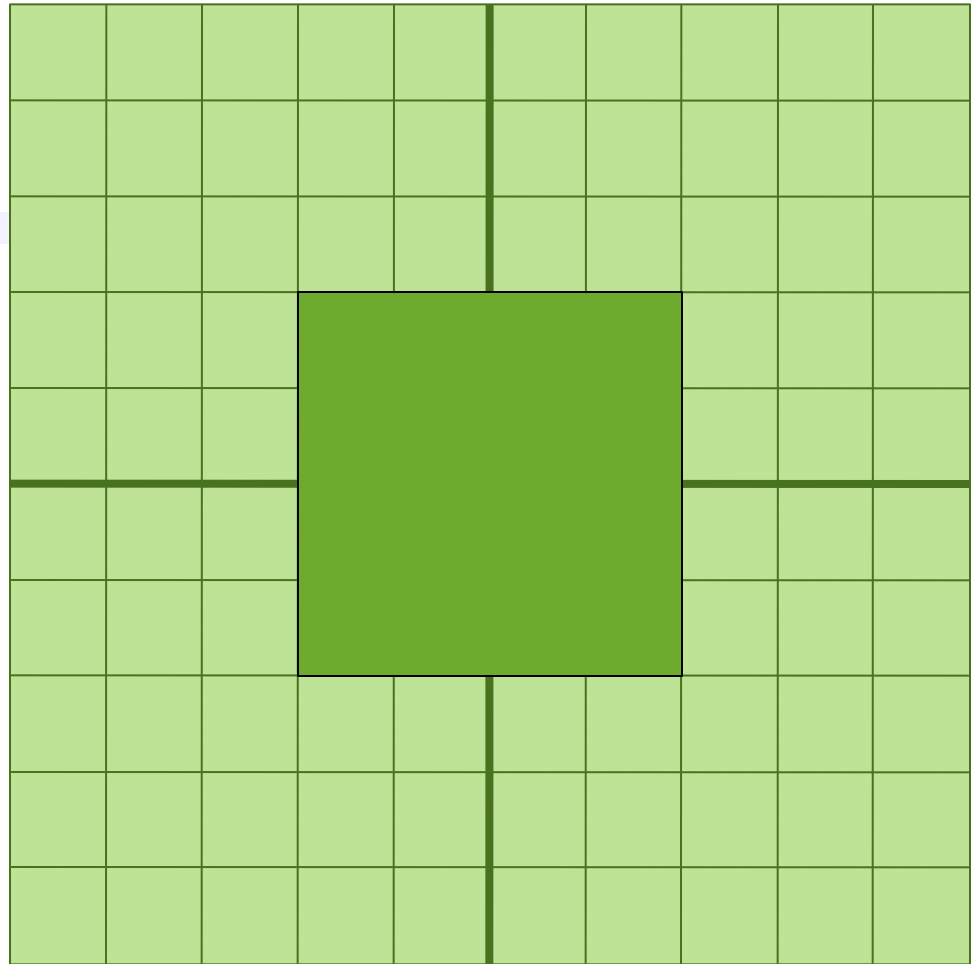
Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```
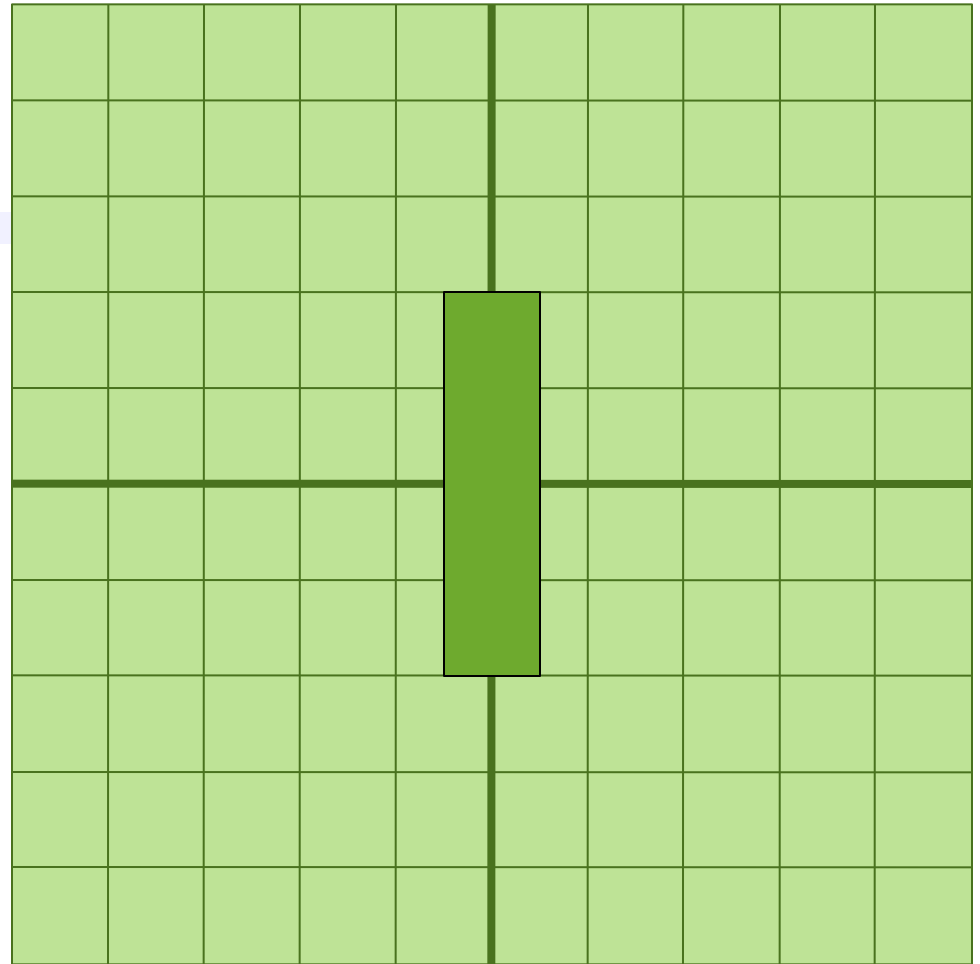
Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

$$\begin{bmatrix} \frac{1}{4} & & & \\ & 1 & & \\ & & \frac{1}{4} & \\ & & & 1 \end{bmatrix}$$
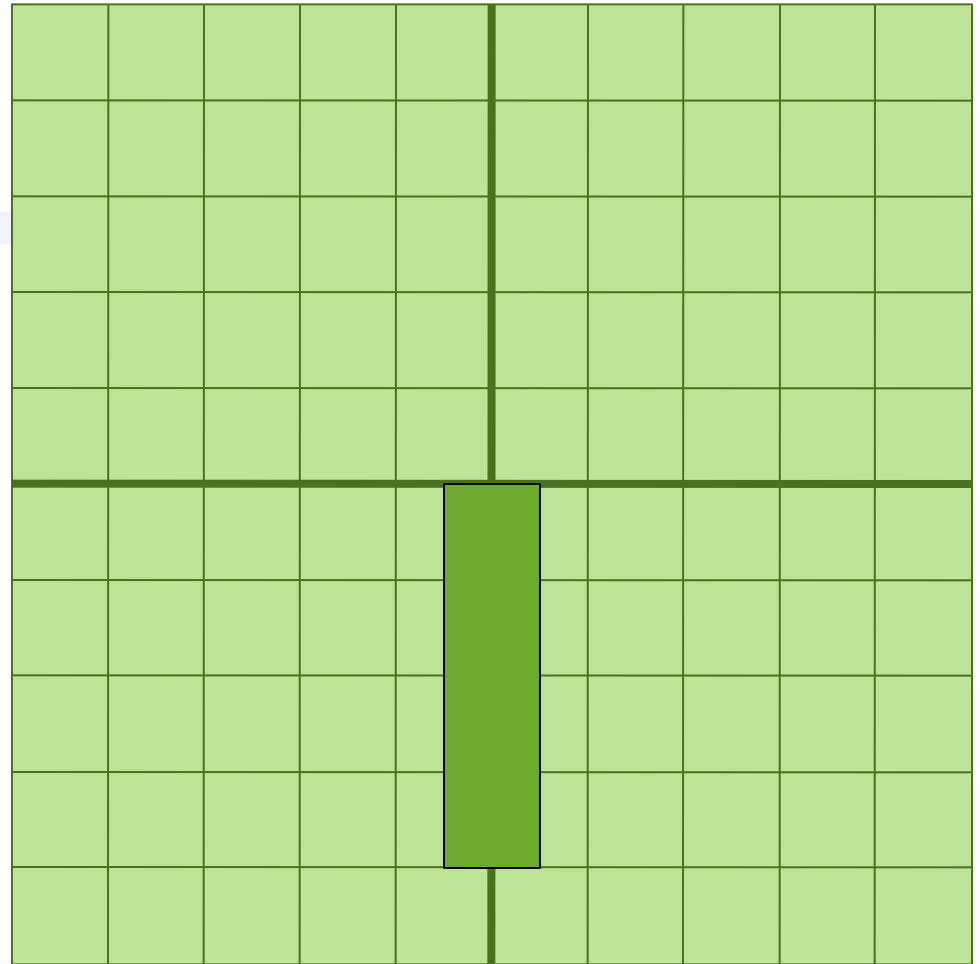
Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

$$\begin{bmatrix} 1 & & & \\ & 1 & & -1 \\ & & 1 & \\ & & & 1 \end{bmatrix} \begin{bmatrix} \frac{1}{4} & & & \\ & 1 & & \\ & & \frac{1}{4} & \\ & & & 1 \end{bmatrix}$$
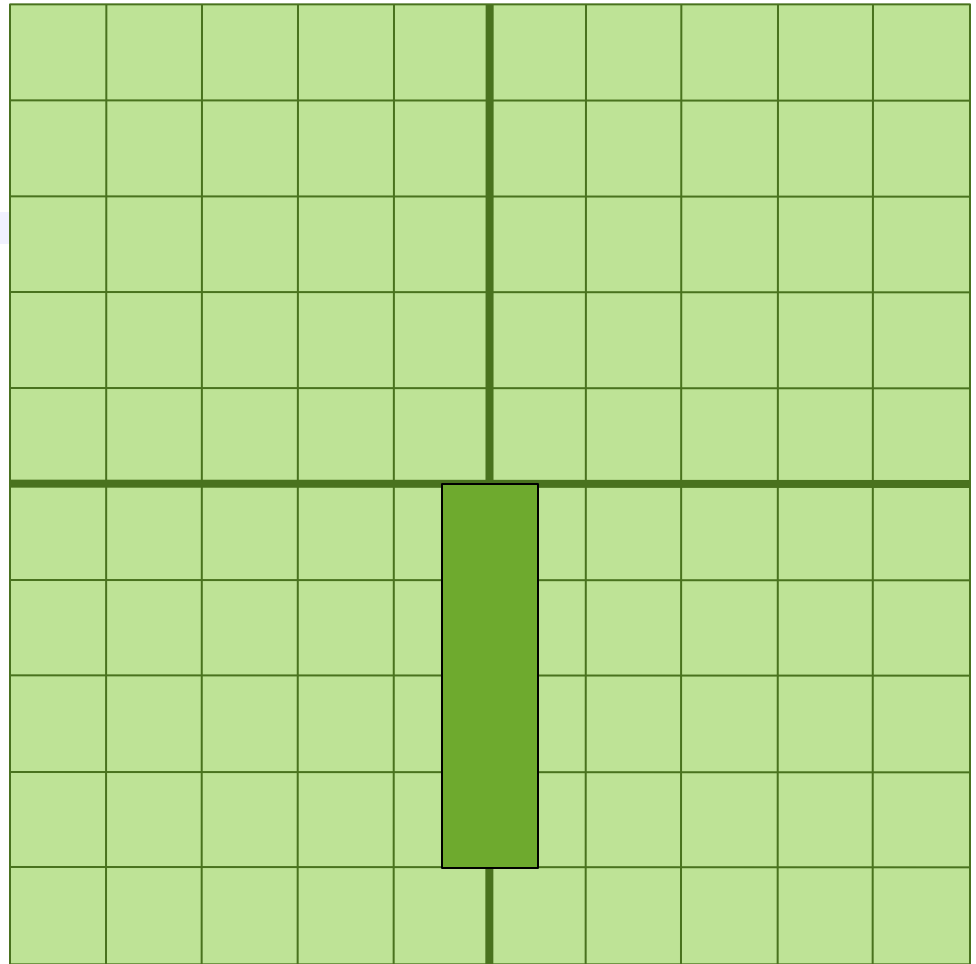
Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```


$$\begin{bmatrix} c & -s & & \\ s & c & & \\ & & 1 & \\ & & & 1 \end{bmatrix} \begin{bmatrix} 1 & & & \\ & 1 & & -1 \\ & & 1 & \\ & & & 1 \end{bmatrix} \begin{bmatrix} \frac{1}{4} & & & \\ & 1 & & \\ & & \frac{1}{4} & \\ & & & 1 \end{bmatrix}$$

Build a Robot


```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```
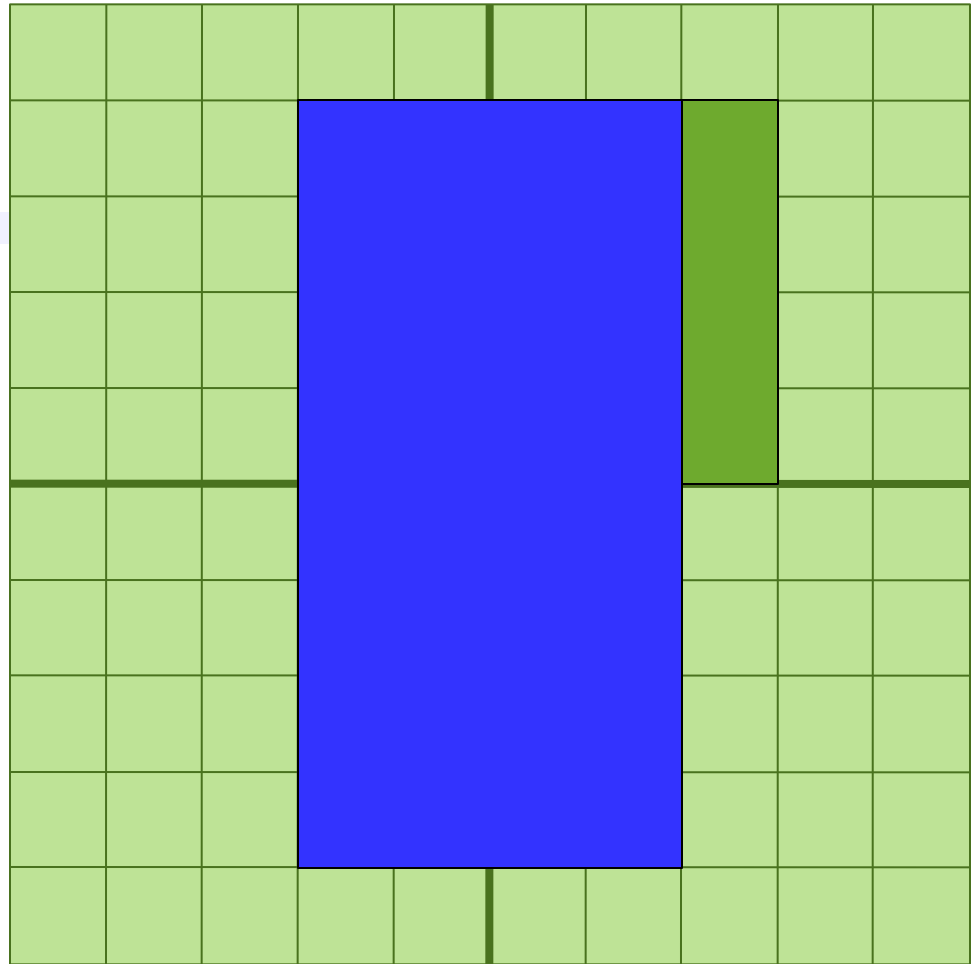
$$
\begin{bmatrix} 1 & & & 1\frac{1}{4} \\ & 1 & & 2 \\ & & 1 & \\ & & & 1 \end{bmatrix}
\begin{bmatrix} c & -s & & \\ s & c & & \\ & & 1 & \\ & & & 1 \end{bmatrix}
\begin{bmatrix} 1 & & & \\ & 1 & & -1 \\ & & 1 & \\ & & & 1 \end{bmatrix}
\begin{bmatrix} \frac{1}{4} & & & \\ & 1 & & \\ & & \frac{1}{4} & \\ & & & 1 \end{bmatrix}
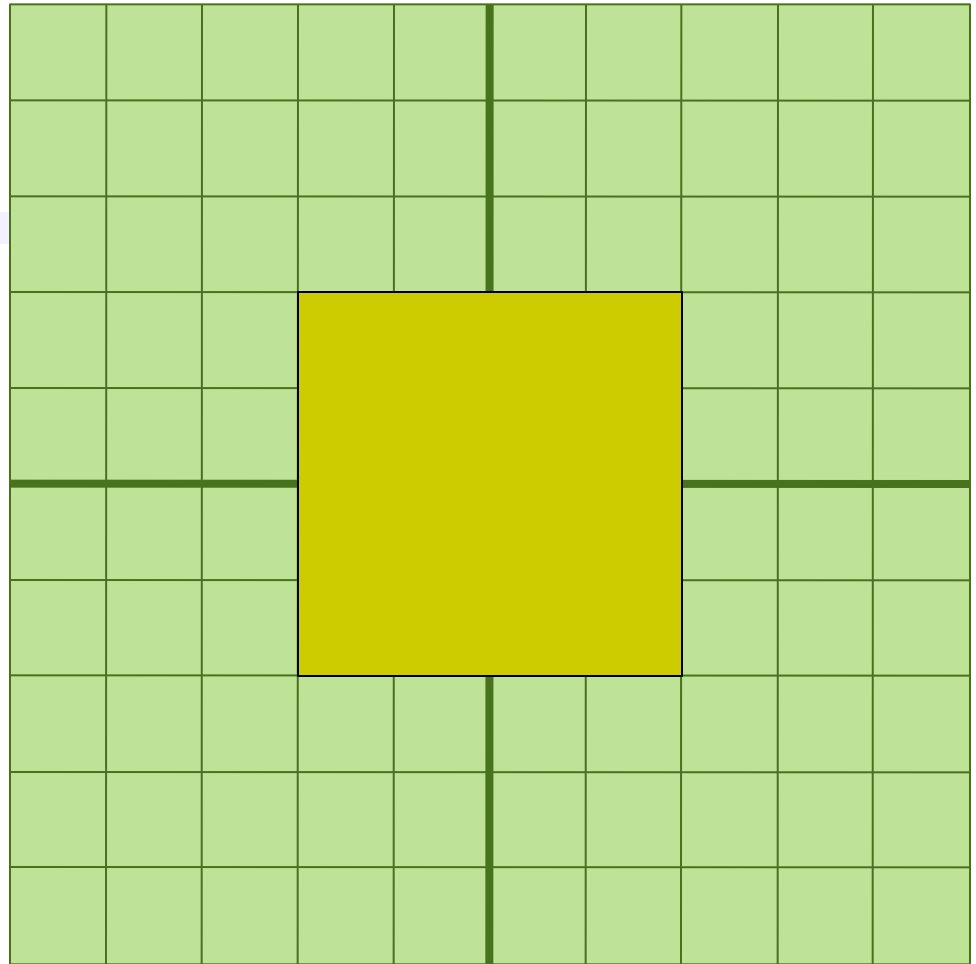$$

Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

push/pop matrix keeps body scale from affecting shoulder

Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```
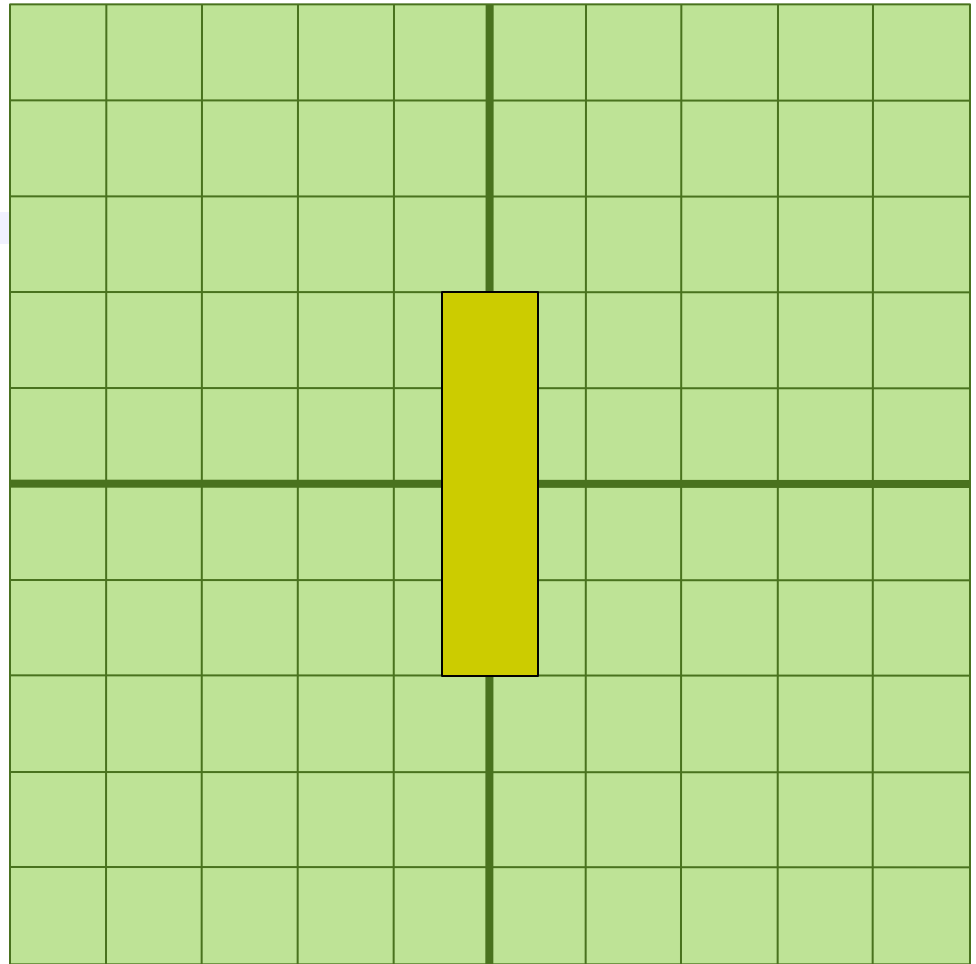
Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```
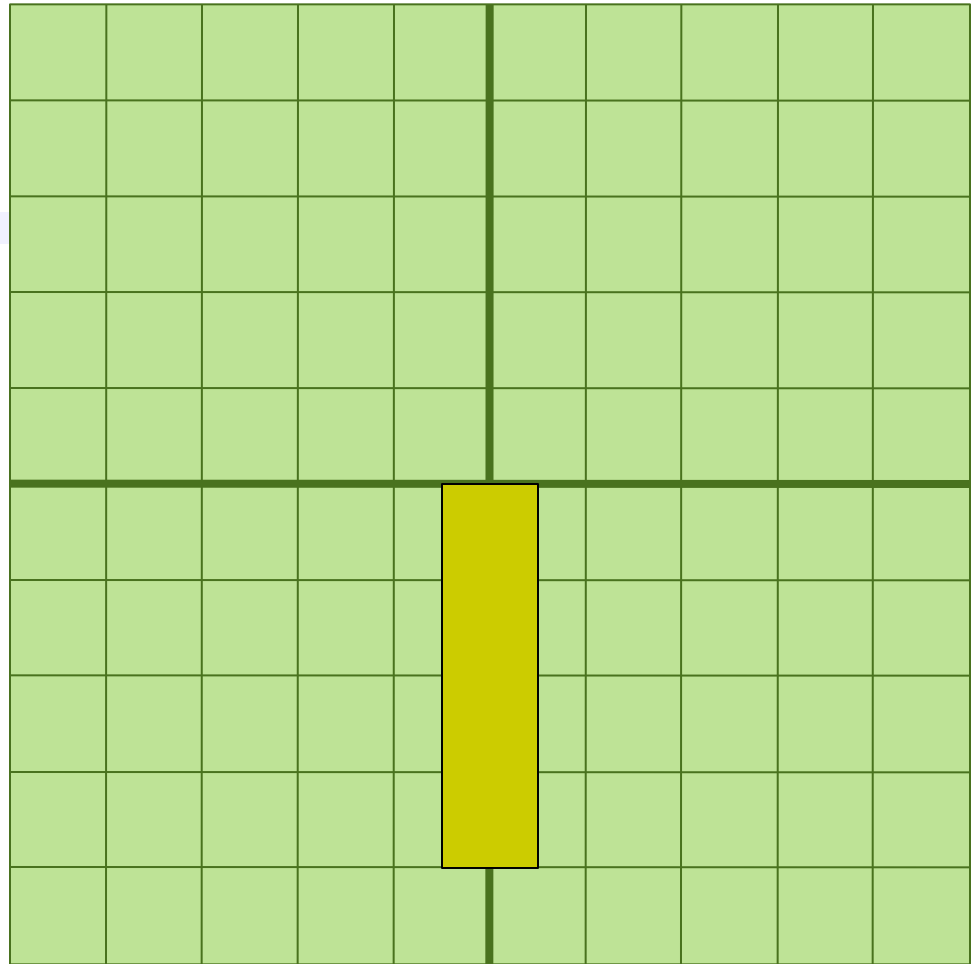
Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```
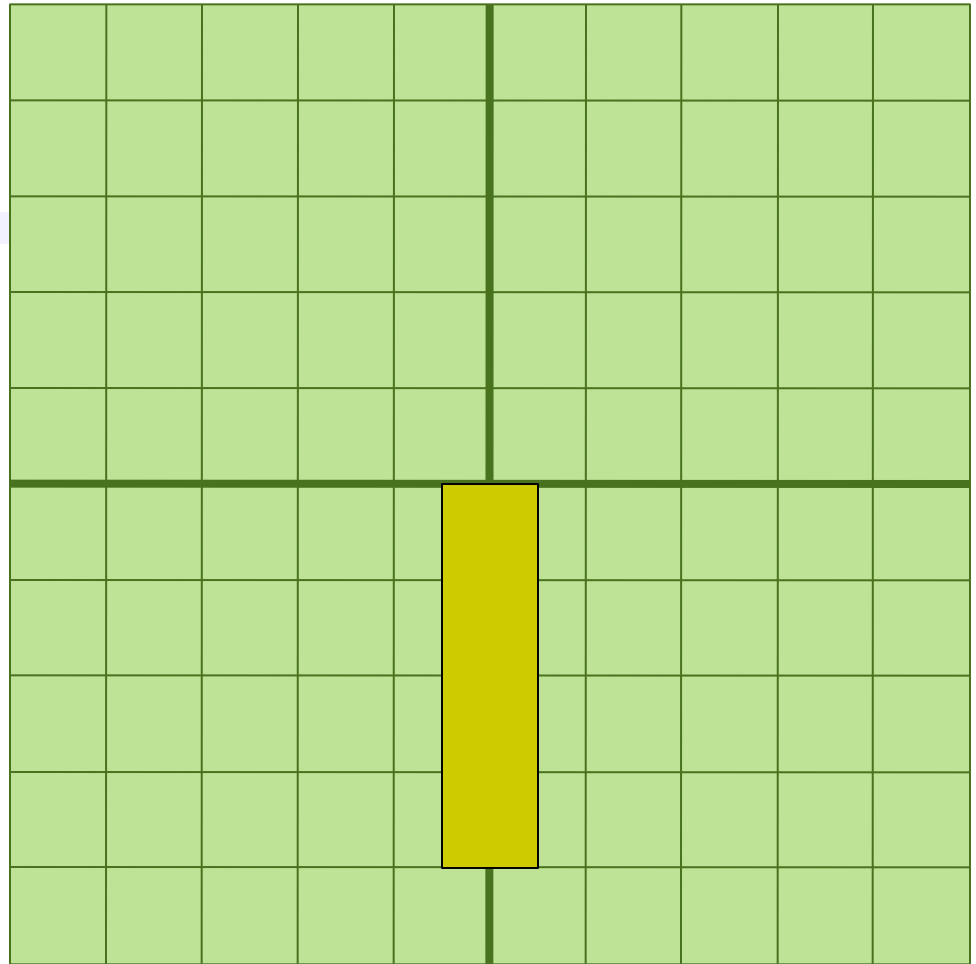
Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```
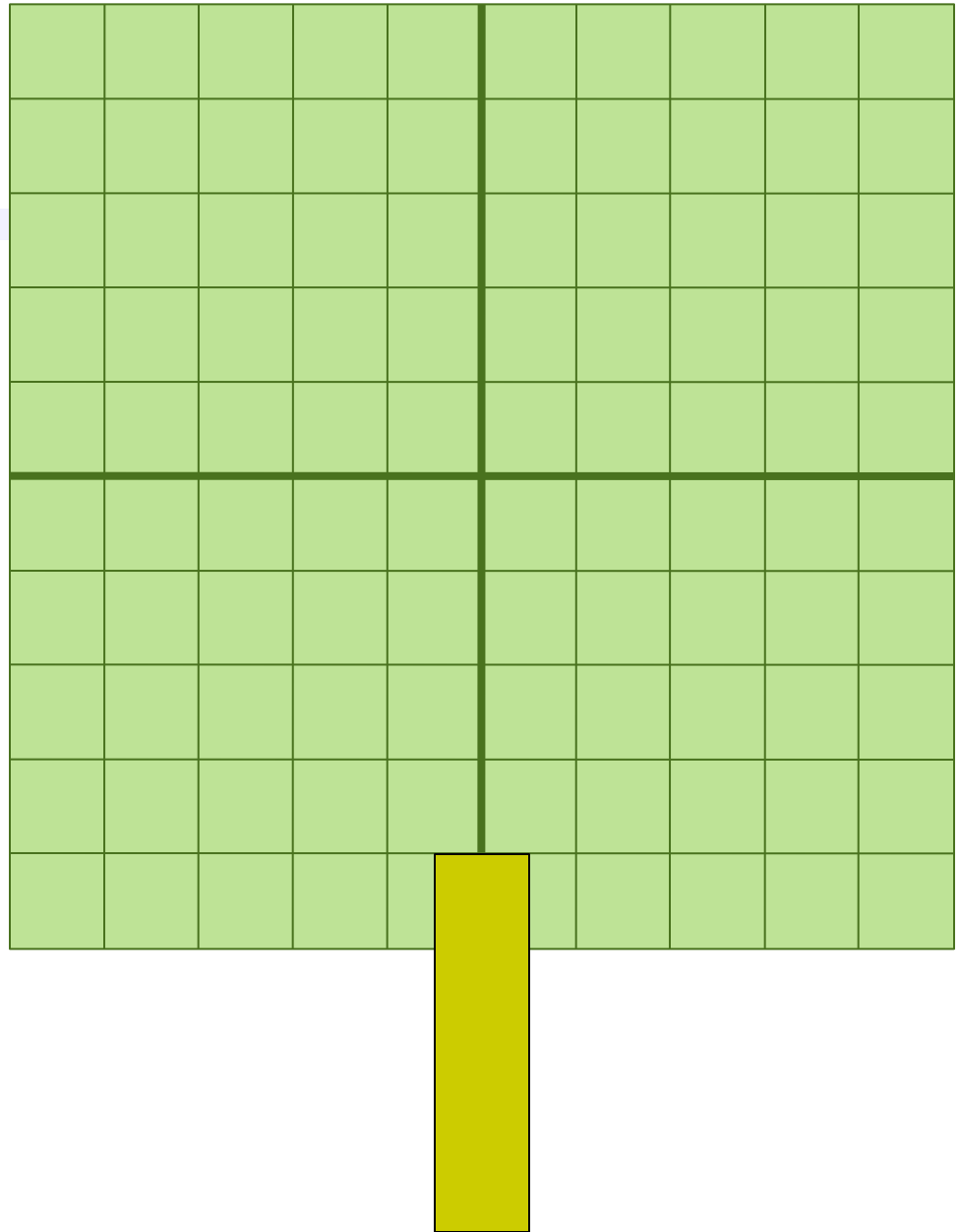
Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

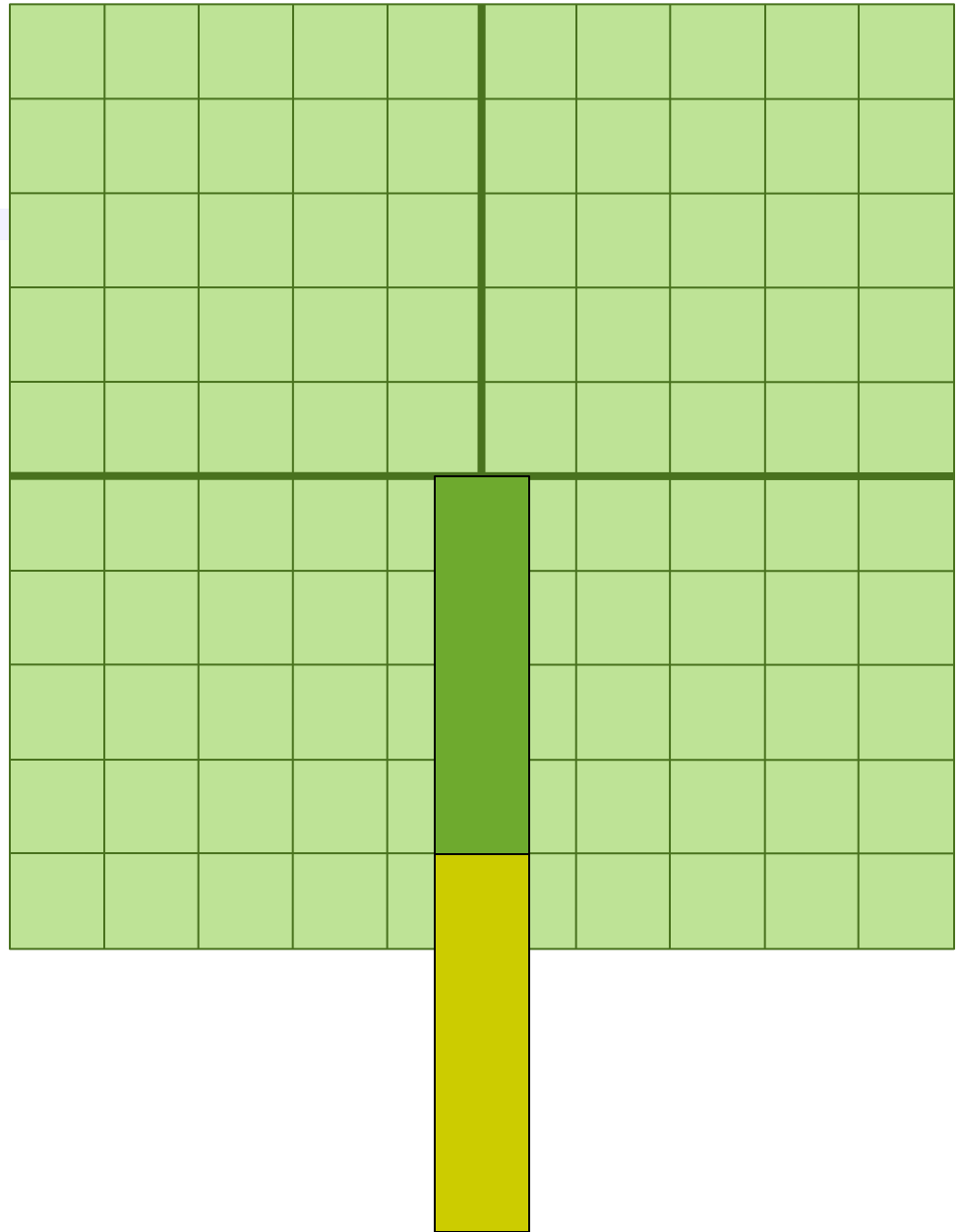*push/pop allows the forearm to ignore these*

Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```
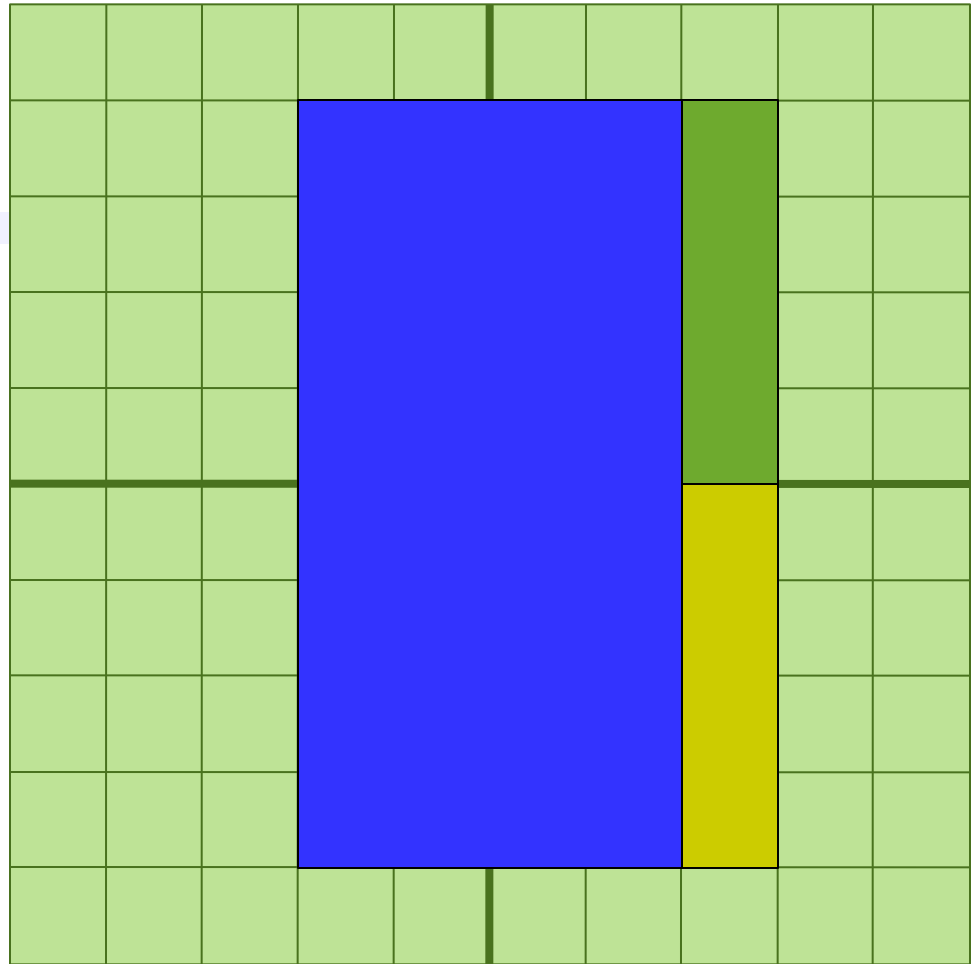
Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```
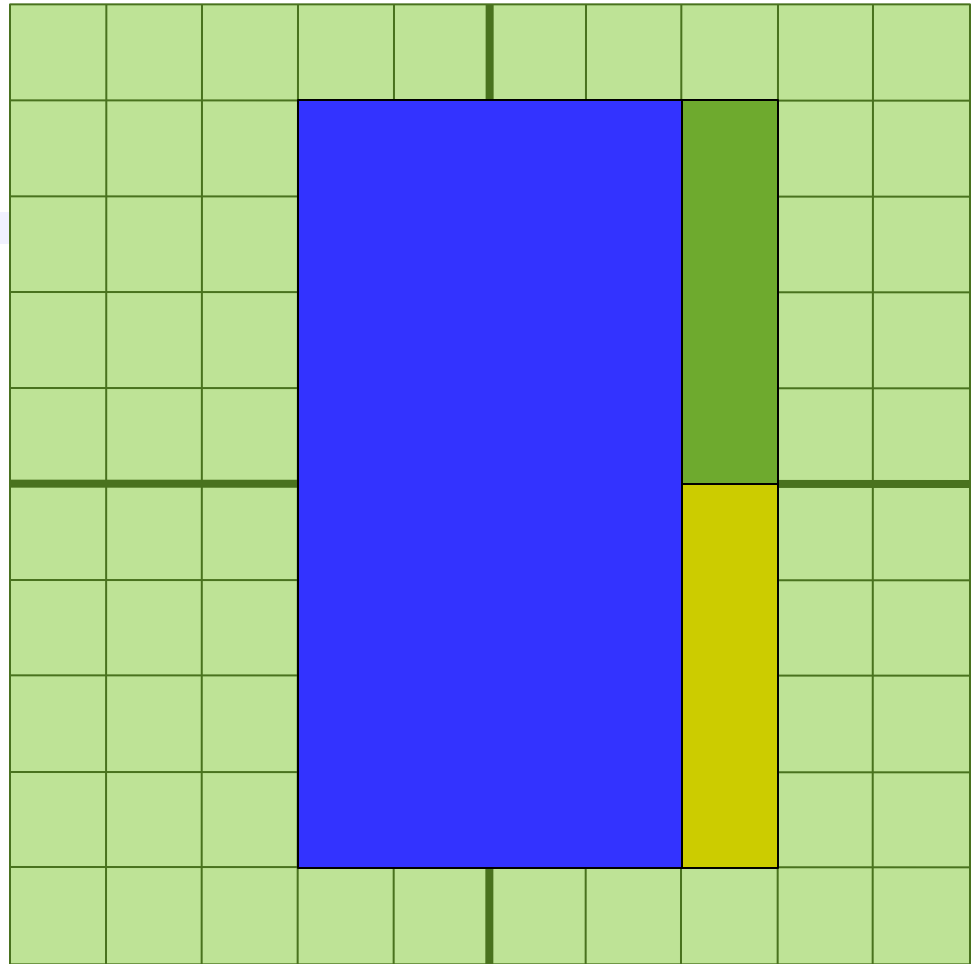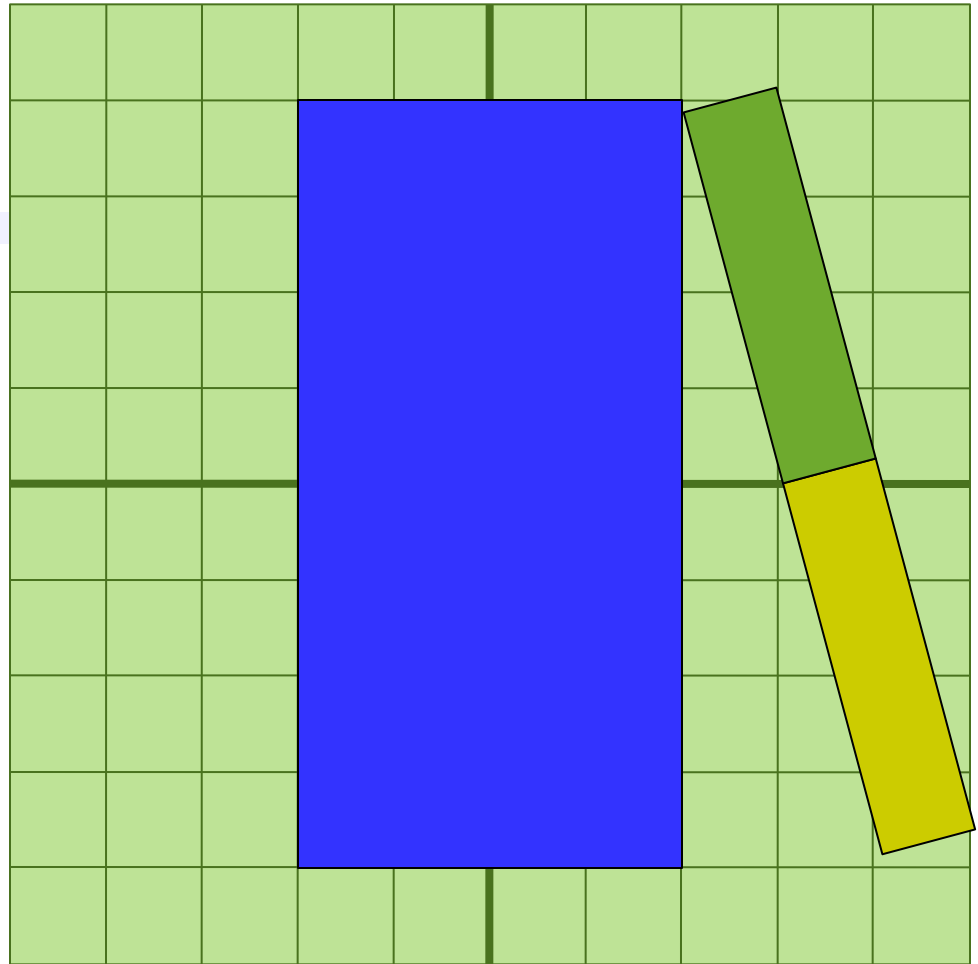
Build a Robot

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Build a Robot

Modelview:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}, \begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$\begin{bmatrix} 1 & & & \\ & 2 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}, \begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$\begin{bmatrix} 1 & & & 1\frac{1}{4} \\ & 1 & & 2 \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$\begin{bmatrix} 1 & & & 1\frac{1}{4} \\ & 1 & & 2 \\ & & 1 & \\ & & & 1 \end{bmatrix}\begin{bmatrix} c & -s & & \\ s & c & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$\begin{bmatrix} 1 & & & 1\frac{1}{4} \\ & 1 & & 2 \\ & & 1 & \\ & & & 1 \end{bmatrix}\begin{bmatrix} c & -s & & \\ s & c & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$\begin{bmatrix} c & -s & & 1\frac{1}{4} \\ s & c & & 2 \\ & & 1 & \\ & & & 1 \end{bmatrix},\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$\begin{bmatrix} c & -s & & 1\frac{1}{4} \\ s & c & & 2 \\ & & 1 & \\ & & & 1 \end{bmatrix}\begin{bmatrix} 1 & & & \\ & 1 & & -1 \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$\begin{bmatrix} c & -s & & 1\frac{1}{4} \\ s & c & & 2 \\ & & 1 & \\ & & & 1 \end{bmatrix},\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$
\begin{bmatrix} c & -s & & 1\frac{1}{4} \\ s & c & & 2-c \\ & & 1 & \\ & & & 1 \end{bmatrix}
\begin{bmatrix} \frac{1}{4} & & & \\ & 1 & & \\ & & \frac{1}{4} & \\ & & & 1 \end{bmatrix}
$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$
\begin{bmatrix} c & -s & & 1\frac{1}{4} \\ s & c & & 2 \\ & & 1 & \\ & & & 1 \end{bmatrix},
\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}
$$

Build a Robot

Modelview:

$$\begin{bmatrix} c & -s & & 1\frac{1}{4} \\ s & c & & 2 \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$\begin{bmatrix} c & -s & & 1\frac{1}{4} \\ s & c & & 2 \\ & & 1 & \\ & & & 1 \end{bmatrix}\begin{bmatrix} 1 & & & \\ & 1 & & -2 \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$\begin{bmatrix} c & -s & & 1\frac{1}{4} \\ s & c & & 2-2c \\ & & 1 & \\ & & & 1 \end{bmatrix}\begin{bmatrix} c' & s' & & \\ s' & c' & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$\begin{bmatrix} cc'-ss' & cs'-c's & & 1\frac{1}{4} \\ c's+cs' & cc'+ss' & & 2-2c \\ & & 1 & \\ & & & 1 \end{bmatrix}\begin{bmatrix} 1 & & & \\ & 1 & & -1 \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$\begin{bmatrix} cc'-ss' & cs'-c's & & 1\tfrac{1}{4}+c's-cs' \\ c's+cs' & cc'+ss' & & 2-2c-cc'-ss' \\ & & 1 & \\ & & & 1 \end{bmatrix}\begin{bmatrix} \tfrac{1}{4} & & & \\ & 1 & & \\ & & \tfrac{1}{4} & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

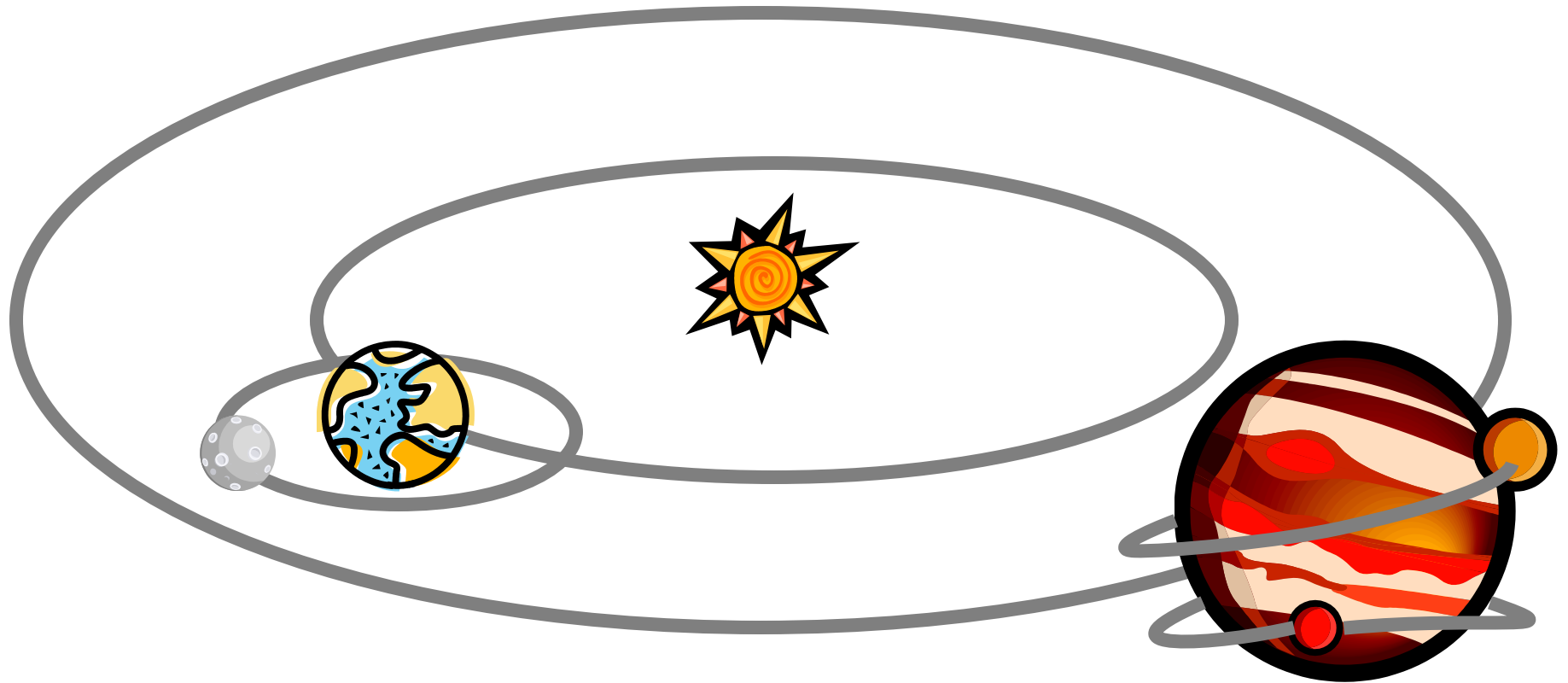$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

Build a Robot

Modelview:

$$\begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

```
glPushMatrix();
glPushMatrix();
glScalef(1.0,2.0,1.0);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(1.25,2,0.0);
glRotatef(shoulder,0,0,1);
glPushMatrix();
glTranslatef(0,-1,0.0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
glTranslatef(0,-2,0);
glRotatef(elbow,0,0,1);
glTranslatef(0,-1,0);
glScalef(0.25,1.0,0.25);
glutSolidCube(2.0);
glPopMatrix();
```

Stack:

Hierarchical Modeling

- Use glPushMatrix() to save a copy of the current coordinate system

- Use glPopMatrix() to return to that coordinate system

- Surround drawing routines with Push/PopMatrix for reusability

  - Better (more reusable) than calling glIdentityMatrix() at the beginning of the display routine, which destroys the current view

```
display() {
    glPushMatrix()
    … establish coordinates …
    glPushMatrix()
    … go off on a tangent …
    glPopMatrix()
    … return to coordinates …
    glPopMatrix()
}

reshape() {
    gluLookat(…)
}
```

Solar System

Solar System

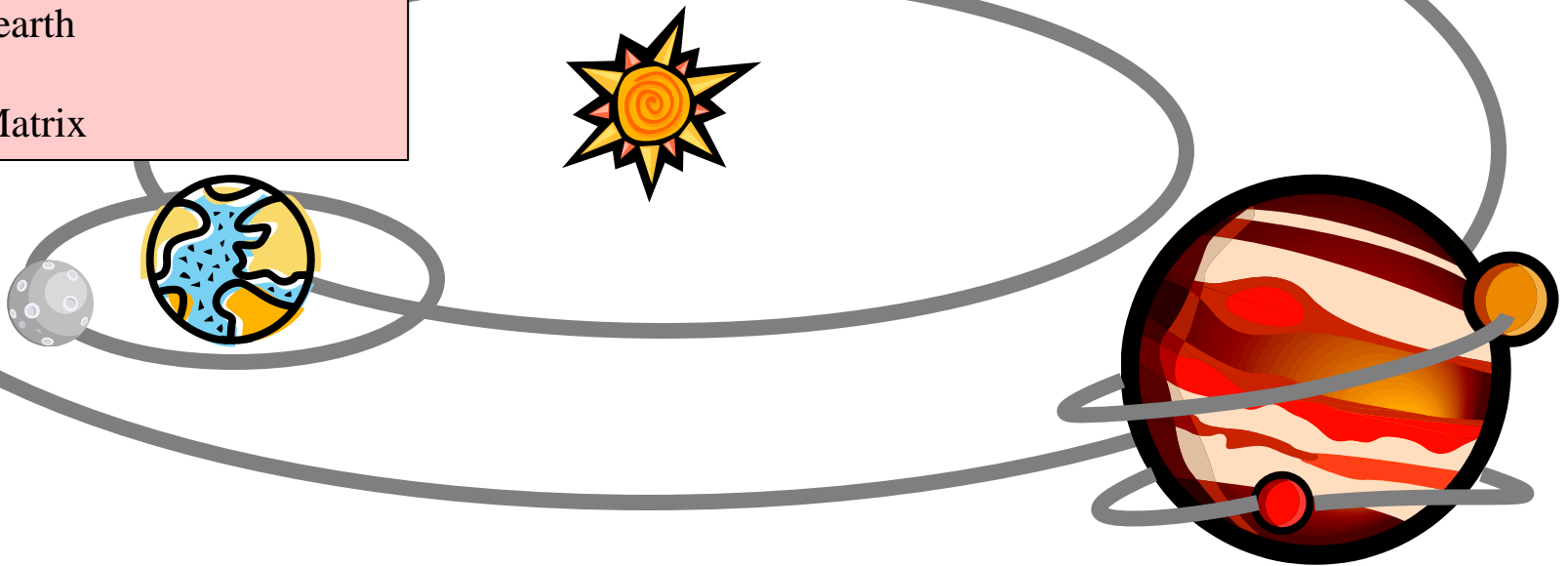PushMatrix
Rotate 360*days/365,(0,1,0)
Translate (AU,0,0)
Rotate 23,(1,0,0)
Rotate 360*hours/24,(0,1,0)
drawearth
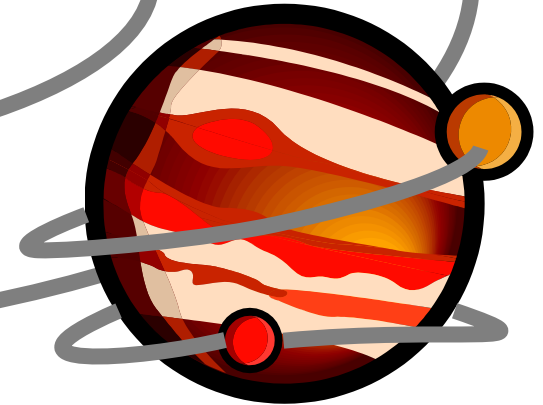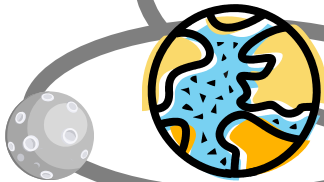…
PopMatrix

Solar System

PushMatrix
Rotate 360*days/365,(0,1,0)
Translate (AU,0,0)
Rotate 23,(1,0,0)
Rotate 360*hours/24,(0,1,0)
drawearth
…
PopMatrix

PushMatrix
Rotate 360*days/27,(0,1,0)
Translate 238856,0,0
Rotate -360*days/29,(0,1,0)
drawmoon
PopMatrix